Marine Geology 403 (2018) 191–196

Contents lists available at ScienceDirect

Marine Geology

journal homepage: www.elsevier.com/locate/margo

Rheological properties of composite serpentine-brucite suspensions: Implications for mudflow behavior on forearc seamounts

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ARTICLE INFO

Editor: G.J. de Lange

Keywords:
Mariana forearc
Seamount
Serpentinite mud
Rheology
Runout distance

ABSTRACT

To better understand the factors that influence seafloor serpentinite mudflows, such as those recently documented on the Marianas seamounts, we have conducted rheological measurements on composite serpentine-brucite suspensions at 7 °C and a salt concentration of 0.6 M. The resulting flow curves were fitted by the Bingham fluid model, from which the Bingham yield stress and plastic viscosity of each suspension was determined. Both the yield stress and plastic viscosity increase as the water content of the suspension decreases. Increasing the brucite fraction in the solid mixture results in an increase in yield stress and a decrease in viscosity of the suspension for the same water/solid ratio. Physicochemical parameters such as pH, temperature and electrolyte concentration also moderately affect the rheology of the suspension, but the influence is not as significant as has been previously observed for suspensions containing smectite. The results suggest that mineral composition of the serpentinite mud, especially the abundance of brucite, has as much of an impact as water content on variable mudflow behaviors such as those observed at the Mariana seamounts.

1. Introduction

Active mud volcanism is a characteristic feature of the Mariana forearc (Fryer, 2012). Large seamounts are thought to have formed along the margin by repeated eruptions, and mudflows commonly occurred on the flanks of the volcanos (Fryer et al., 2006). Sampling of the seafloor by dredging and drilling has revealed that the mudflows commonly comprise comminuted and fragmented serpentinized mantle peridotite (Fryer and Mottl, 1992; Lagabrielle et al., 1992; Fryer et al., 1999). Active serpentinite seamounts have not yet been found in other subduction margins, but they may have been more common in the past (Fryer et al., 2000). Precise knowledge of the mudflow behaviors allows us to understand the emplacement mechanism of the serpentinite deposits that are now distributed in orogenic belts worldwide (Lockwood, 1971, 1972; Fryer et al., 2000).

Serpentinite mudflows on the Mariana seamounts display a wide range of flow-related morphological features and rock types (Fryer et al., 2006). For example, comparison of the Conical and S. Chamorro seamounts demonstrates that the flow features of the former are more evident and larger scale than the later; some flow lobes on the flanks of the Conical seamount extend > 18 km from the summit (Fryer et al., 2006). A large sector collapse on the southern flank of S. Chamorro has a runout distance > 70 km (Fryer et al., 2000), but this deposit lacks a mud matrix enclosing fragments (Fryer, 1996), suggesting that it was probably a rock avalanche rather than a mudflow. Based on these observations, Fryer et al. (2006) argued that the S. Chamorro seamount serpentinite mud was more viscous than that of the Conical seamount. This inference is also supported by the absence of a distinct summit knoll on the Conical seamount. Fryer et al. (2006) also suggested that this difference in mud rheological properties might be related to different water contents in the erupted muds, which results in lower measured chlorinity pore fluids in the Conical seamount mud (i.e., seawater freshening; Mottl et al., 2003). Another contrasting feature is that the S. Chamorro mud compositions are more variable than those of the Conical seamount (Fryer et al., 2006). Although the mud matrix samples collected from the two seamounts are both dominantly composed of the serpentine minerals chrysotile and lizardite, only those from the S. Chamorro seamount also contain abundant brucite; commonly 20–50 wt% as determined by semi-quantitative X-ray diffraction (XRD) analysis (Shipboard Scientific Party, 2002; Lagabrielle et al., 1992). As well as water content, the rheological properties of the mud suspension are influenced by factors such as mineralogy and physicochemical conditions (Mitchell and Soga, 2005).

In this study, we have conducted rheological measurements on serpentine suspensions in order to determine what factors can produce variable serpentinite mudflow behaviors. Given that brucite content

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https://doi.org/10.1016/j.margeo.2018.06.004
Received 26 September 2017; Received in revised form 7 June 2018; Accepted 10 June 2018
Available online 13 June 2018
0025-3227/

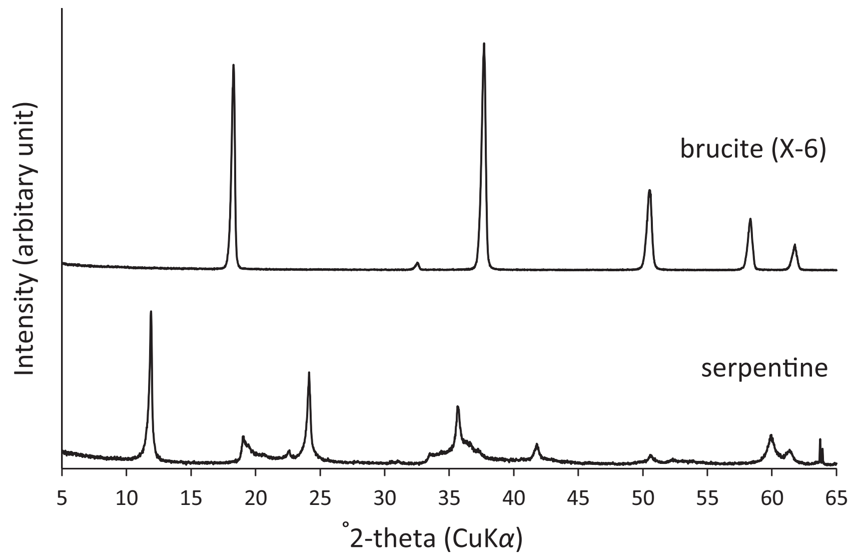

Fig. 1. XRD patterns for specimens of brucite (X-6) and serpentine.

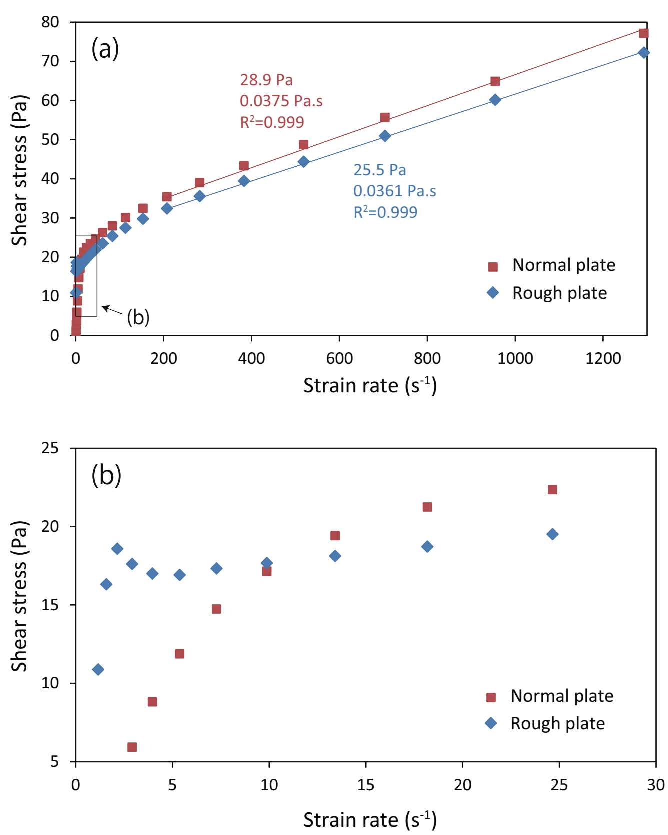

Fig. 2. (a) Typical flow curves (strain rate vs. shear stress) for suspension of 56% water content with 80 wt% of serpentine + 20 wt% of brucite. Red and blue plots were data obtained by using the normal and rough plate, respectively. The yield stress and plastic viscosity were determined by fitting the data using the Bingham fluid model (solid lines). (b) Enlarged curves of (a) for strain rate from 0 to 30 s^{-1}. A stress peak appeared when sheared using the rough plate. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

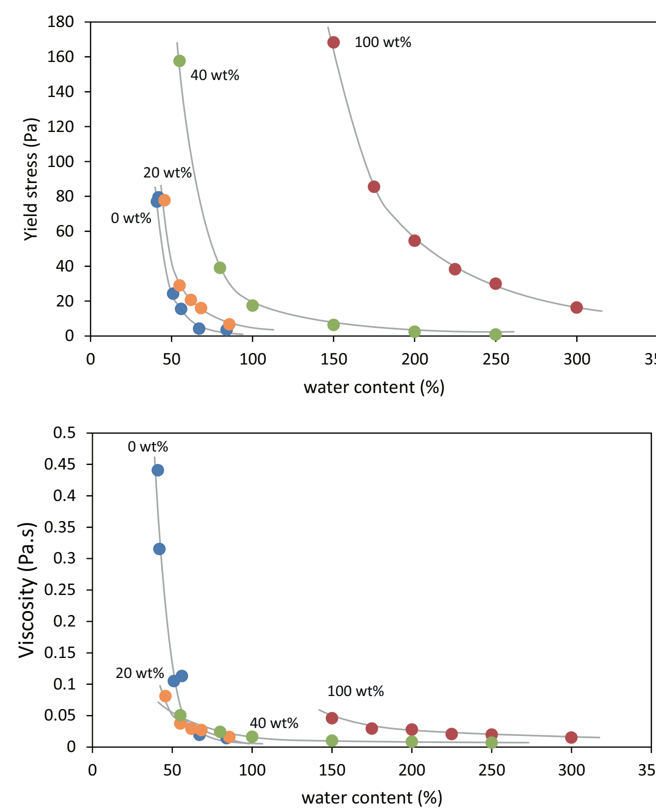

Fig. 3. Summary plots for yield stress-water content (upper panel) and viscosity-water content (lower panel) as a function of brucite fraction in the solid component.

also varies in the mudflow samples at the different localities, we especially focus on how the suspension rheology depends on brucite fraction in the suspended solids. The results inform discussion of potential causes of the differences in observed mudflow behaviors on the Mariana seamounts.

2. Methods

2.1. Materials and sample preparation

A serpentine powder was prepared from a mixture of natural lizardite and chrysotile collected from the Mineoka ophiolite, central Japan (Hirauchi et al., 2010). The rock chip was crushed in a tungsten mortar and passed through a 100 μm sieve. A XRD pattern of the